Nonideality of Ground

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Ground is supposed to be ideal. It should be a black hole for stray currents where the voltage is always zero. Unfortunately, those stray currents travel through some non-superconducting material, so small voltages arise. You may not notice small changes in ground potential, you may, instead, notice surplus noise or instability or other unwanted attributes in your system. We are going to discuss ground. Every circuit is unique and grounding paths are different for every device on your board and in your system. Therefore, we are starting with an intuitive approach to try and give you a feel for the paths currents choose to travel and how that affects the ideal assumption of ground being zero volts.

First, remember that circuits are only complete when current has a complete path to travel (that is why a switch can be placed anywhere along that path to interrupt flow and function). The power supply creates a potential difference, a push, for the current if a path exists for it to travel. Assuming a single-supply system, it's natural for us to ensure that the positive supply connection is as short and clean as possible. We add bypass capacitors-sometimes multiple values and types of bypass capacitors-to filter the power supply voltage where it enters every critical chip. Then, since there is a ground pin on our IC, we dutifully hook it to a grounded wire or ground plane. For many of us, that's the last we think about ground... unless there's a problem.

One of the common methods for tracking down a problem is to probe important nodes in the circuit with a digital multimeter. If that doesn't illuminate the problem, try probing ground in a variety of places. You might be surprised with what you find. The ground in a system is quite like the ground we find in nature. There are holes from burrowing animals and there are a variety of materials from sand, clay, soil and types of rock. The consistency and structure of the materials affects how things like water, animals and tree roots travel through the ground. All three of these travelers chose the path of least resistance. They naturally avoid, or travel around, obstacles in their path.

In circuits, there are many factors that can affect flow in the ground plane. For example, the purity of the metal composing the plane and the consistency with which is it applied to the printed circuit board. There are vias connecting to or through the ground plane. There are currents from other ICs making their way through ground to the power supply.

Ever wonder why we place bypass capacitors as close to the IC as possible? They provide a high-frequency path to short any high frequencies that may exist or even be gathered on the power supply line. (A copper wire is a fine dipole antenna. The frequencies it picks up are strongly dependent on the length of the trace and/or wire.) Earlier we referenced the practice of probing nodes with a DMM. When referring to the placement of bypass capacitors, it would be more revealing to probe with an oscilloscope. Not only will you find frequencies that circulate in your system, you will likely find signals from local radio stations or one of the many wireless transmissions surrounding our everyday lives. These are the signals that couple in through longer traces and wreak havoc on the operations of our systems. Not only do they exist on power supply lines, they circulate in the ground, too.

An example of bypass capacitor placement is shown in Figure 1. The SOT-23 package pads in the center will hold an op amp. There is a bypass capacitor connected on each of the dual supply pins. Notice that the opposite sides of the capacitors are connected to ground. The ground connection is not a long wire eventually connecting to the ground plane. Instead, a large rectangle of top layer metal allows high frequency currents to easily coast through two nearby vias to the ground plane.

Once the unwanted signals reach the ground plane, they don't magically disappear. They continue to travel through the ground plane. It is on this journey that they can couple into other signals in the system and affect more than just the IC with the long trace. To see how the current travels, refer to Figure 2. You'll notice that the op amp layout in Figure 1 is duplicated twice on the inputs of the circuit in Figure 2. We now follow the current through the ground connection we highlighted as a common connection between the bypass capacitors in Figure 1. The majority of the current takes a direct path to the ground pins of the input connector. However, notice how the density of the current spreads. It travels in a wider arc that you might imagine. Now superimpose the paths of signals through every other ground via back to the connector grounds. (If we tried to draw them all on another figure, it would look more like fireworks.) That is how signals from one IC couple to another and how interference signals can couple into every part of your system.

Notice that two characteristics will affect the spreading of the current and the shape of the return path. The first is distance. The drive to make consumer products smaller greatly helps with this aspect. However, as the printed circuit boards get smaller, the devices get closer together. Distance is reduced, but now the multiple ground return paths are closer together. When the fringes of current overlap, the signals intertwine.

What can we do? Careful layout is a must. Keep high frequency circuitry as compact as possible. You might even choose to isolate these devices with metal traces or cuts in ground planes. Figure 3 gives you an example. The return current of input A no longer overlaps with the return current of input B. In this case, knowing the nonideal nature of ground allows us to improve the operation of our system. A full ground “plane” will not work as well as one with cuts to guide the return current. If we had assumed ground was ideal, we would have not have been able to make this improvement.

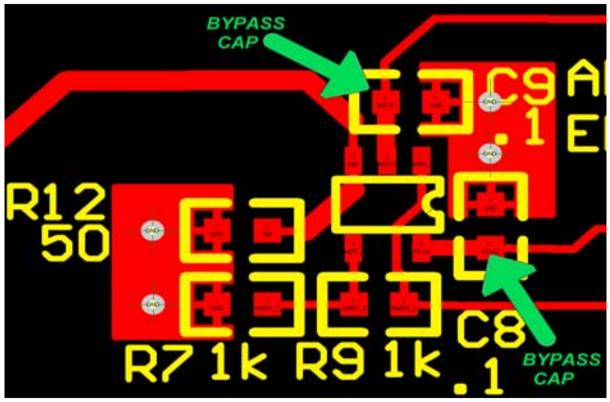

FIGURE 1. THE LOCATION OF BYPASS CAPACITORS ARE HIGHLIGHTED IN A LAYOUT OF AN OP AMP IN A SOT-23 PACKAGE

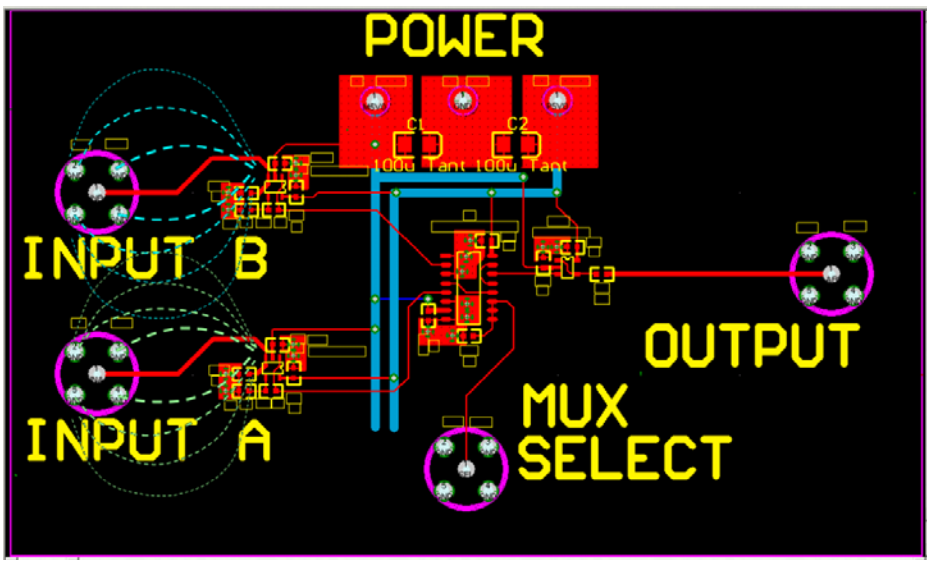

FIGURE 2. AN EXAMPLE PRINTED CIRCUIT BOARD LAYOUT WITH TWO INPUTS TO TWO SEPARATE OP AMPS FEEDING A MULTIPLEXER. THE GREEN DASHED LINES SHOW AN EXAMPLE PATH THAT SIGNALS TAKE THROUGH THE GROUND PLANE BACK TO THE GROUND PINS OF THE INPUT CONNECTOR. THE LONGER THE GREEN DASHES, THE HIGHER THE CONCENTRATION OF GROUND CURRENT

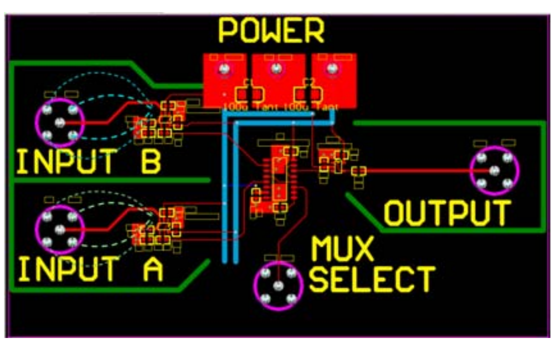

FIGURE 3. CUT-OUTS IN THE GROUND PLANCE ELIMINATE ANY CROSSTALK BETWEEN THE RETURN GROUND PATHS OF INPUT A AND INPUT B

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